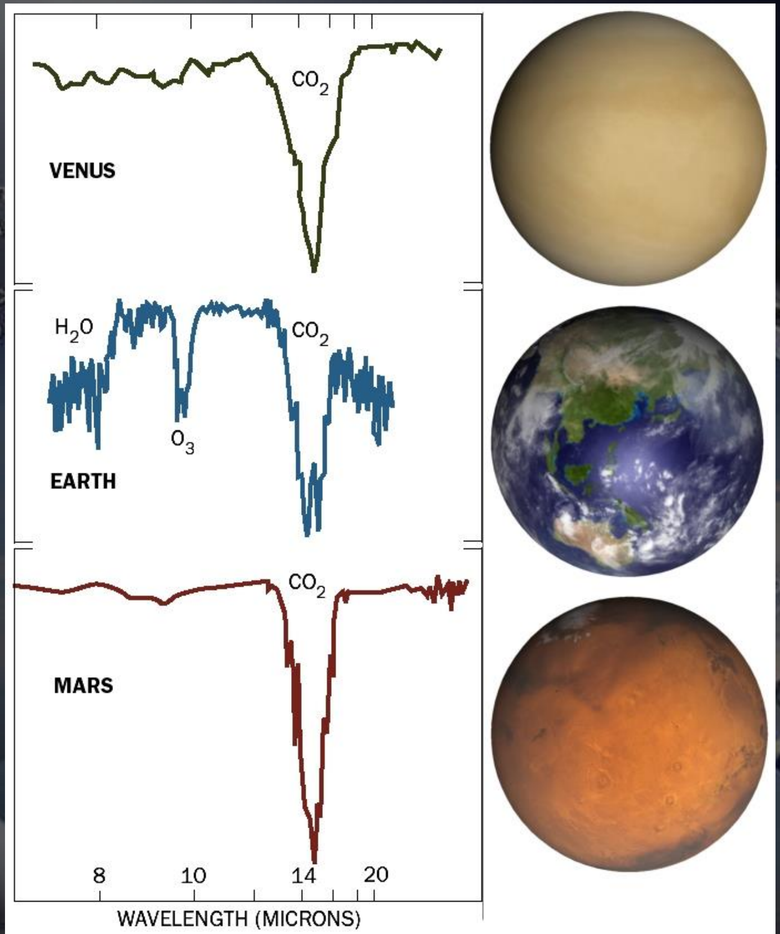
Oxygenic phototrophs exposed to simulated exoplanetary conditions: possible biosignatures in different organisms

Elisabetta Liistro[1], Beatrice Boccia[1], Mariano Battistuzzi[1], Lorenzo Cocola[2], Luca Poletto[2], Nicoletta La Rocca[3]

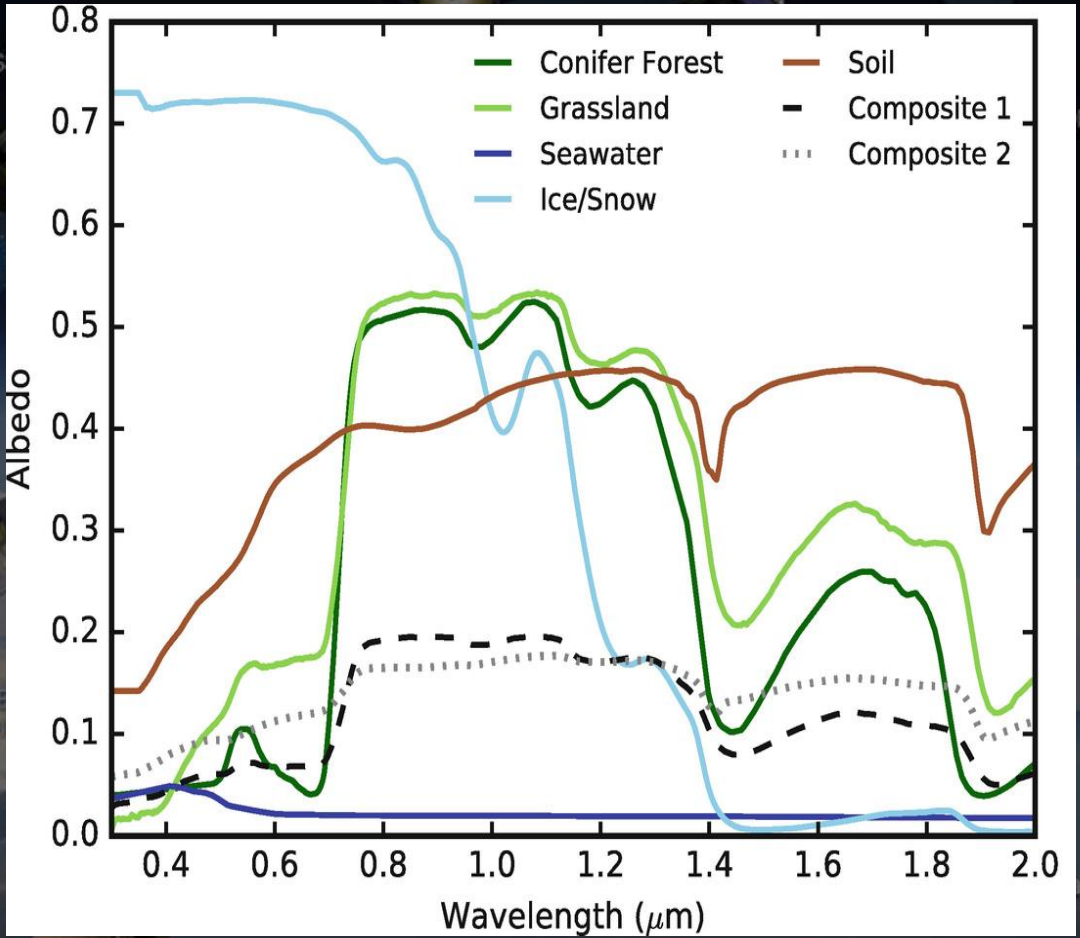
[1] Department of Biology, University of Padova, Padova, Italy
[2] Institute for Photonics and Nanotechnologies, CNR, (CNR-IFN), Padova, Italy


National Aeronautics and Space Administration
Exoplanet Missions
[1] NASA/ESA Partnership
[2] NASA/ESA/CSA Partnership
[3] CNES/ESA
[4] ESA/Swiss Space Office
[5] NSF Partnership (NN-EXPLORE)
Hubble[1]
Spitzer [retired]
Kepler/K2 [retired]
TESS
JWST[2]
Roman
Habitable Worlds Observatory
NASA Missions
CoRoT[3] [retired]
Gaia
CHEOPS[4]
PLATO
ARIEL (CASE[1])
ESA Partner Missions
ASTERIA [retired]
CUTE
SPARCS
Pandora
NASA Cube/Small Satellites
Ground Telescopes with NASA Participation
W. M. Keck Observatory
Large Binocular Telescope
WIYN[5]
SMARTS 1.5m[5]
MINERVA-Australis[5]
www.nasa.gov

Looking for life beyond planet Earth: the search for biosignatures



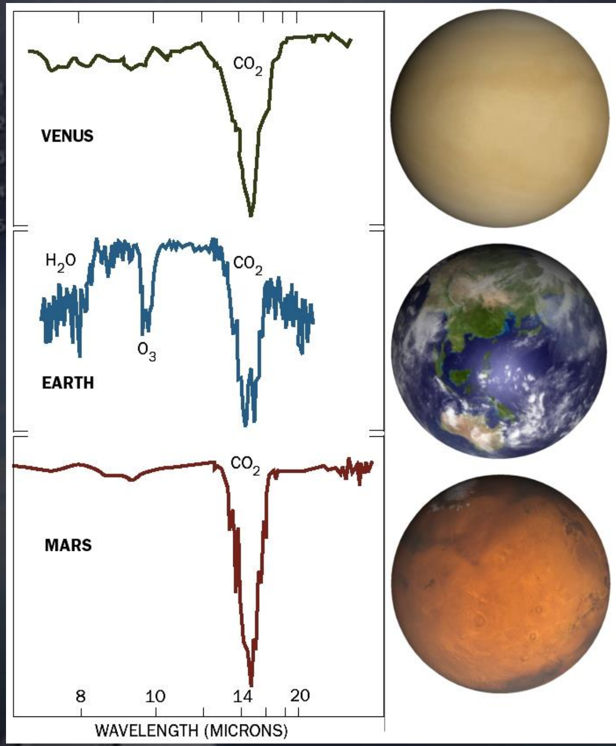
Atmospheric biosignatures



Surface biosignatures

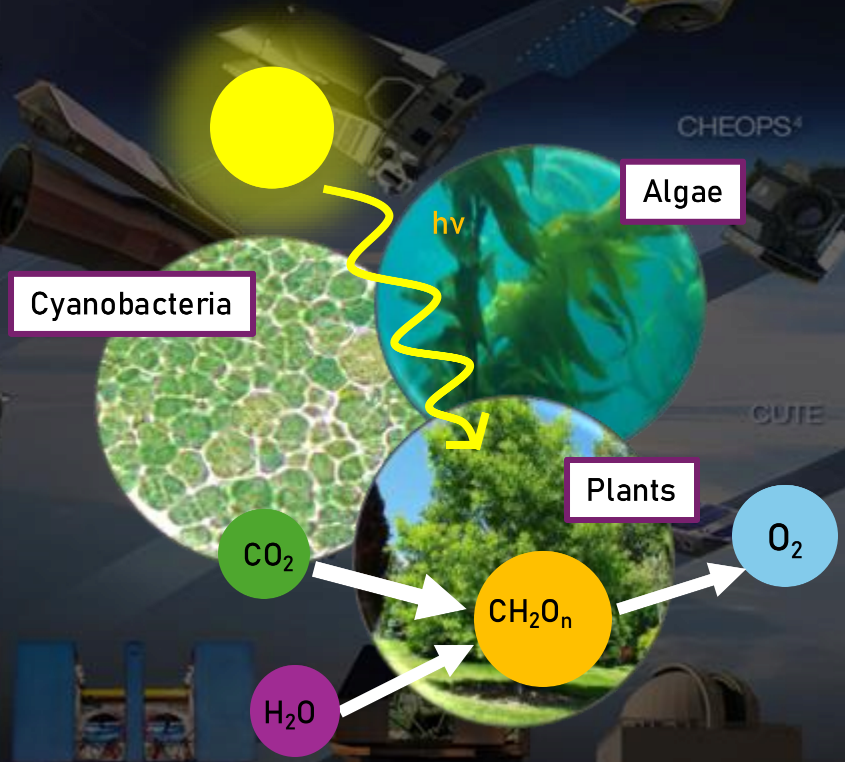
Schwieterman 2018

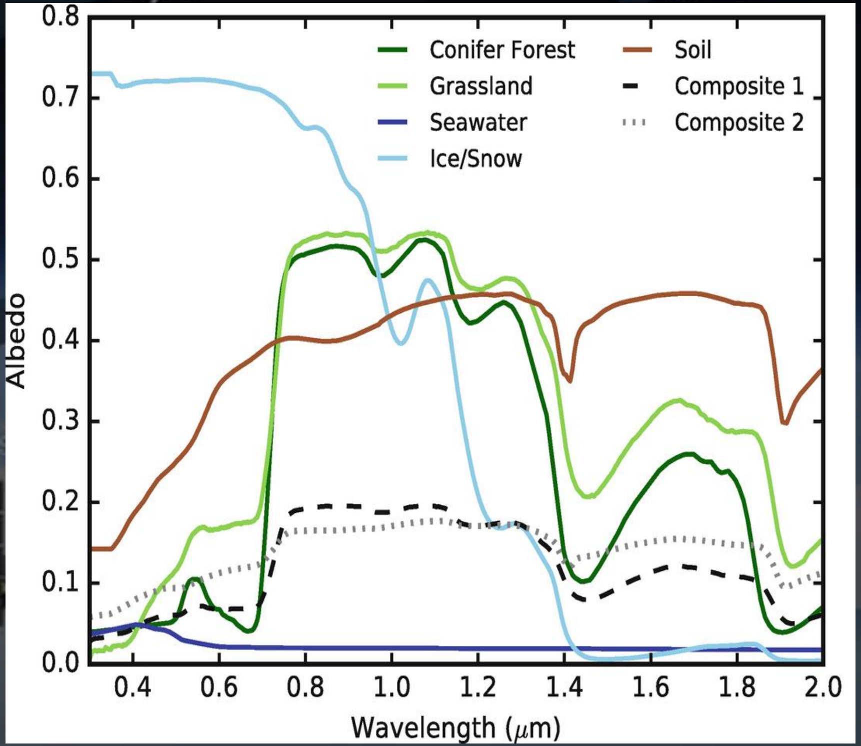
Looking for life beyond planet Earth: the search for biosignatures



Atmospheric biosignatures

Oxygenic photosynthesis produces strong biosignatures on our planet



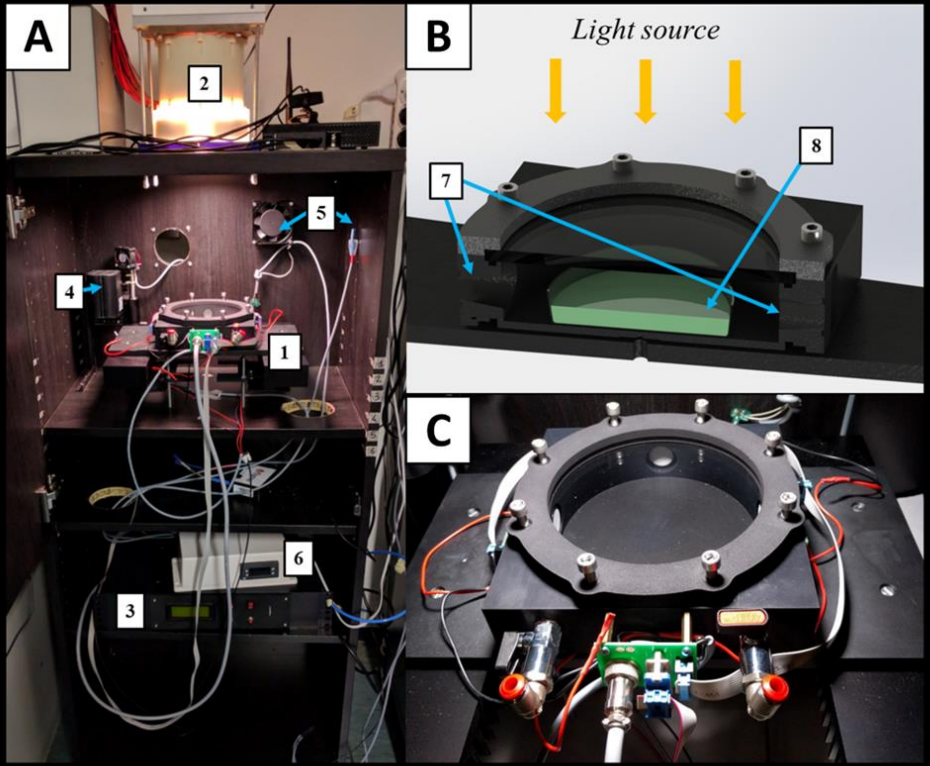


Surface biosignatures

Schwieterman 2018

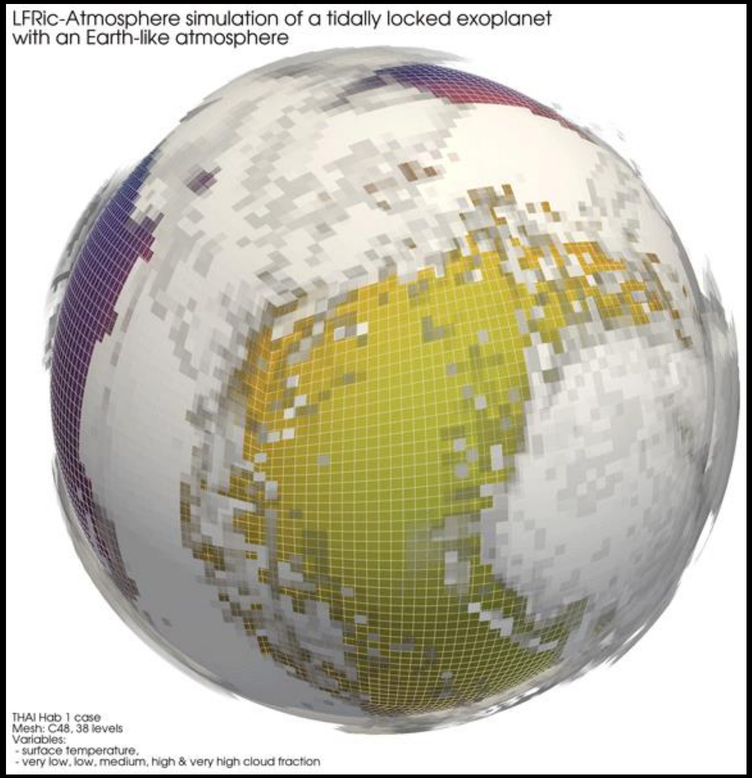
Guiding exoplanet observations for the search for biosignatures

Laboratory simulations

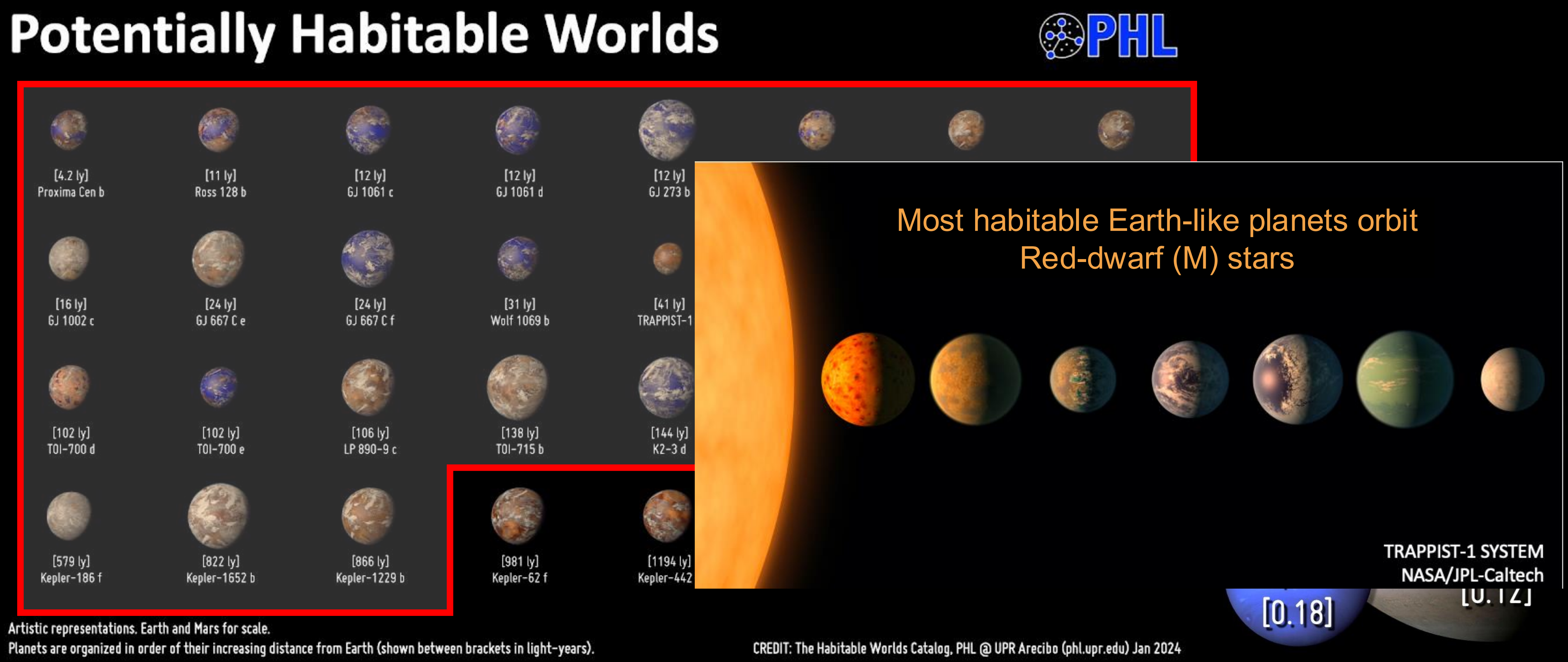


Battistuzzi et al 2023

Numerical simulations

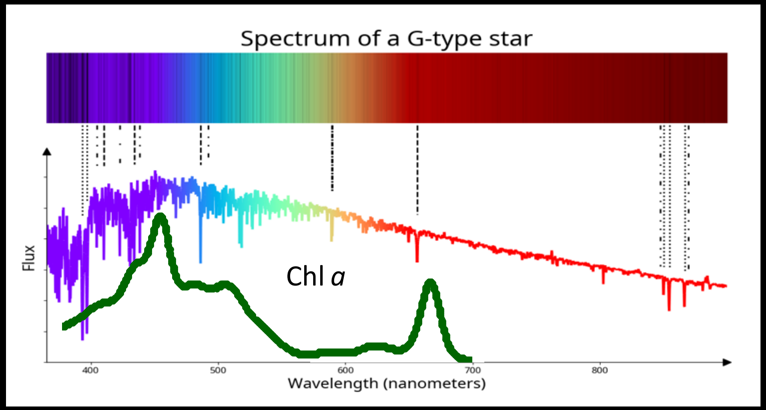


Sergeev et al., 2023 Geoscientific Model Development

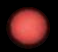


Most habitable Earth-like planets orbit Red-dwarf (M) stars

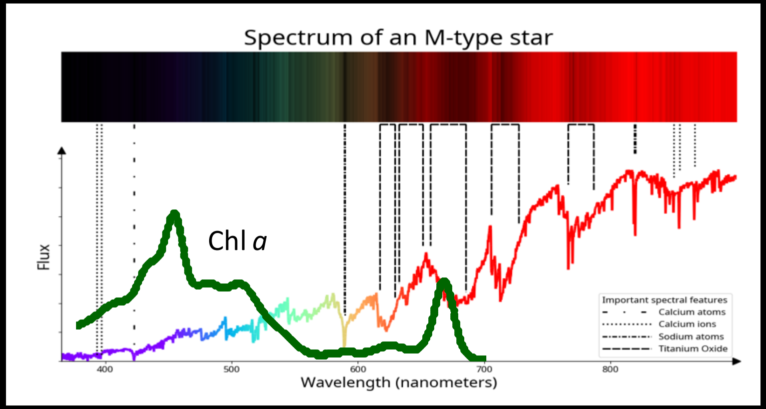
G spectral type (e.g. Sun)



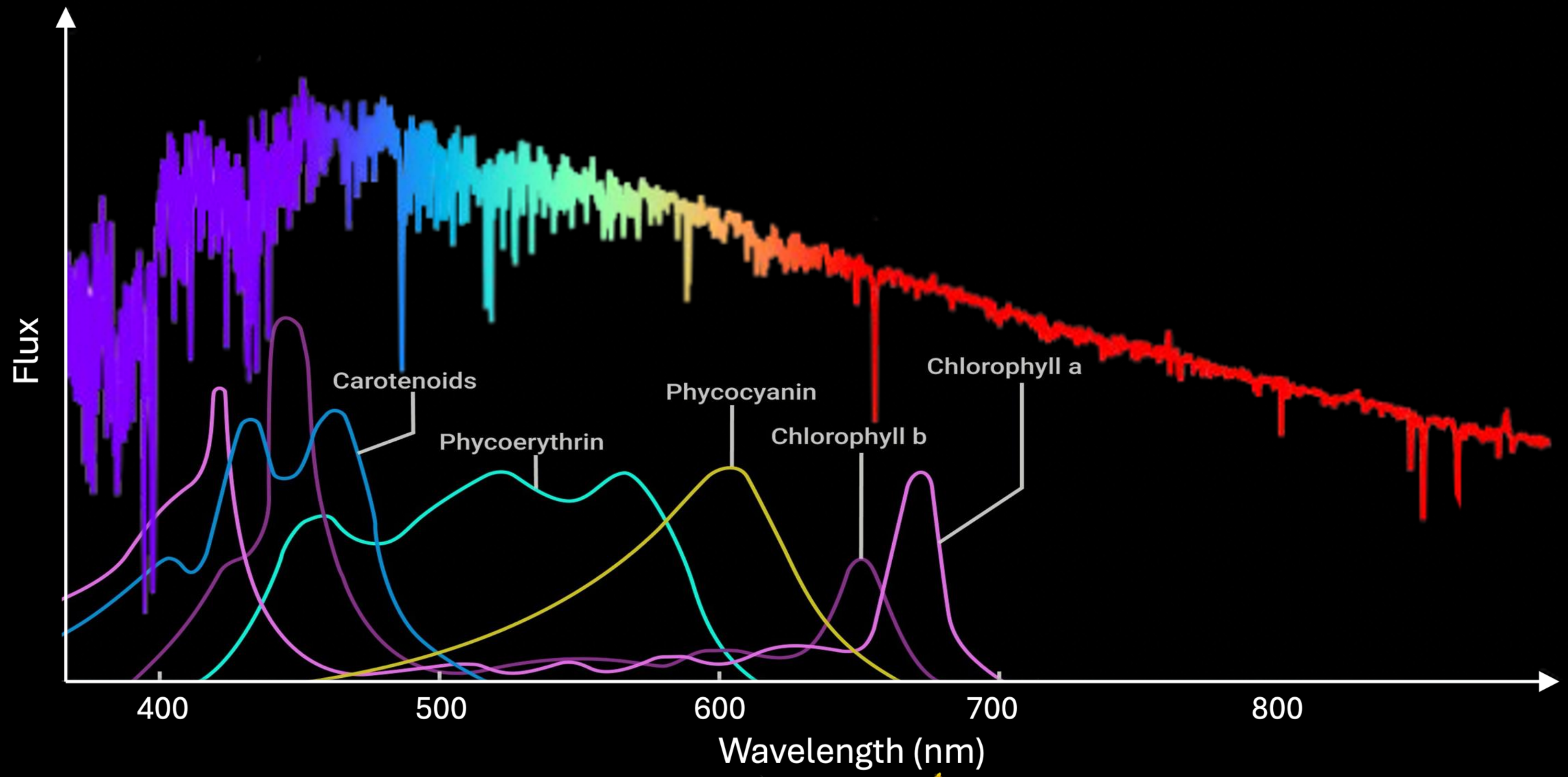
Spectral Class	Effective Temperature [K]	Luminosity [$L_\odot$]	Mass [$M_\odot$]	Radius [$R_\odot$]	Abundance [%]	Life Duration [Byr]
G	5.200 – 6.000	0.6 – 1.5	0.8 – 1.04	0.96 – 1.15	7.6	10
K	3.700 – 5.200	0.08 – 0.6	0.45 – 0.8	0.7 – 0.96	12.1%	17 - 70
M	2.400 – 3.700	$\leq$ 0.08	0.08 – 0.45	$\leq$ 0.7	76.45	250



M spectral type
(e.g. Trappist-1 and Gliese 12)

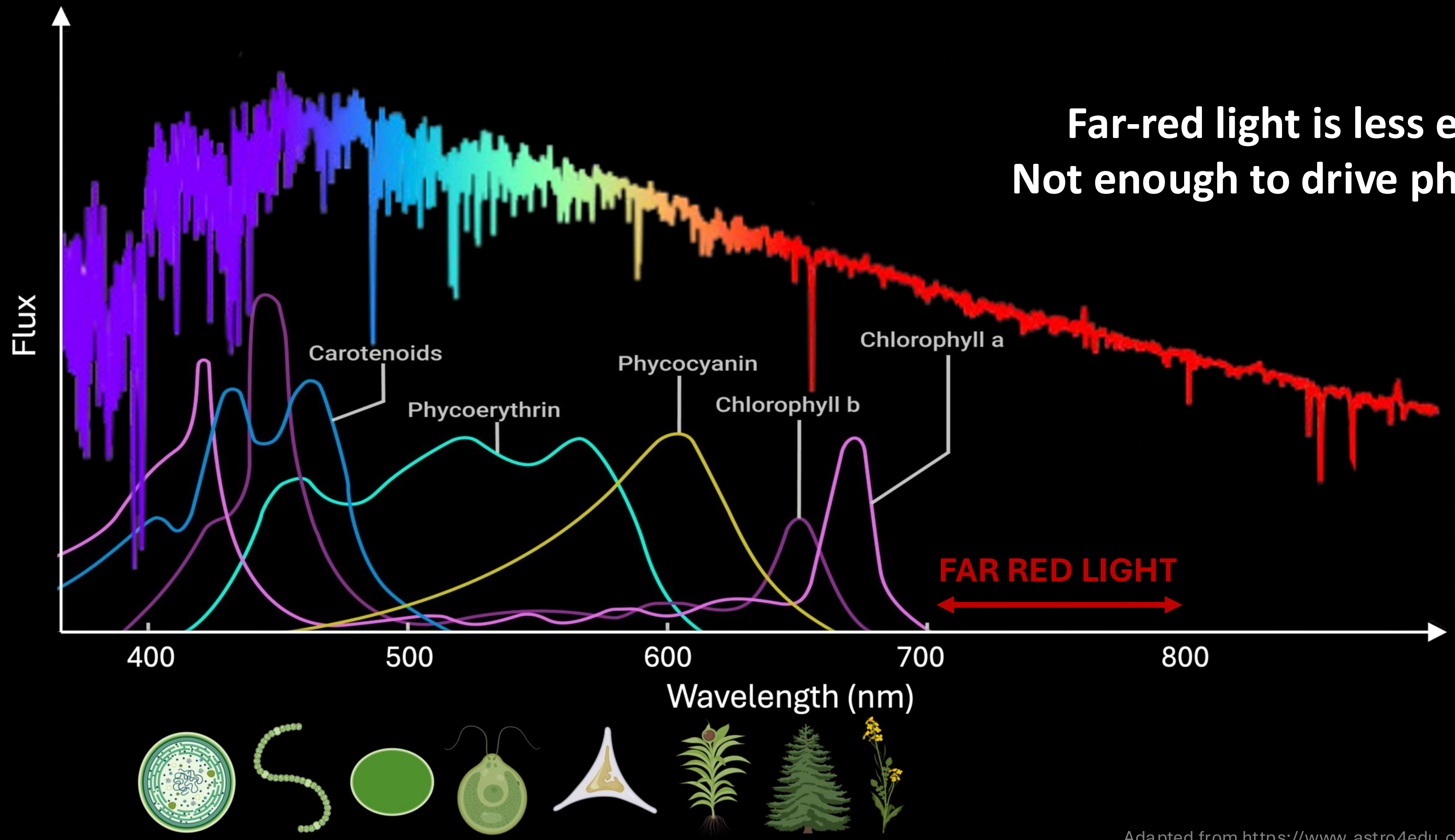


Sun emission spectrum and photosynthetic light harvesting pigments



Adapted from https://www.astro4edu.org/de/resources/diagram/Tt35DR10il63/

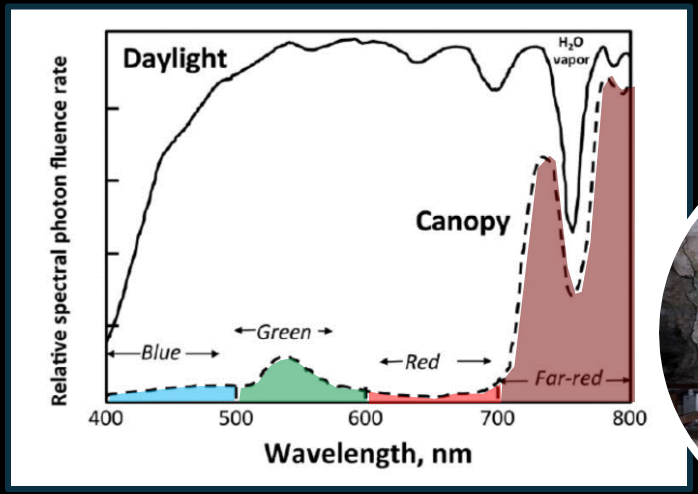
Sun emission spectrum and photosynthetic light harvesting pigments



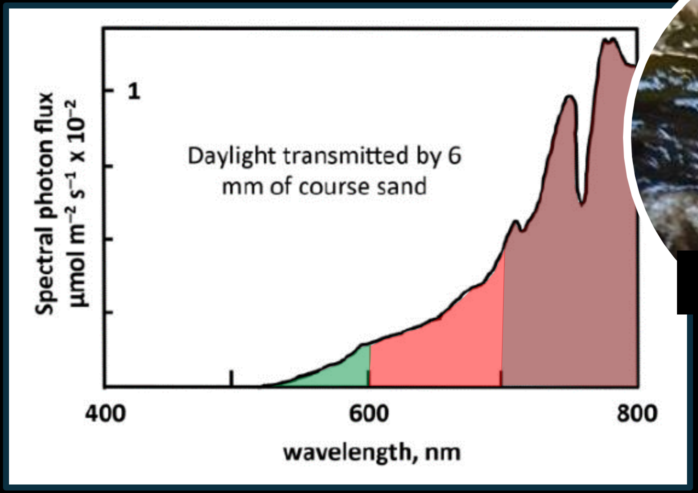
Far-red light is less energetic…
Not enough to drive photosynthesis

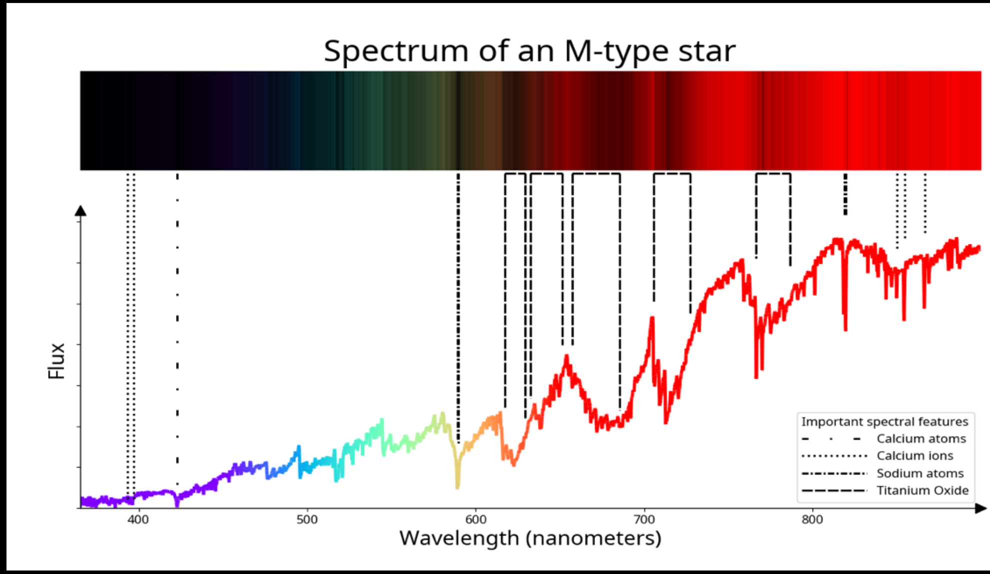
Adapted from https://www.astro4edu.org/de/resources/diagram/Tt35DR10il63/

Exoplanet’s light analogues: niches enriched in far-red light

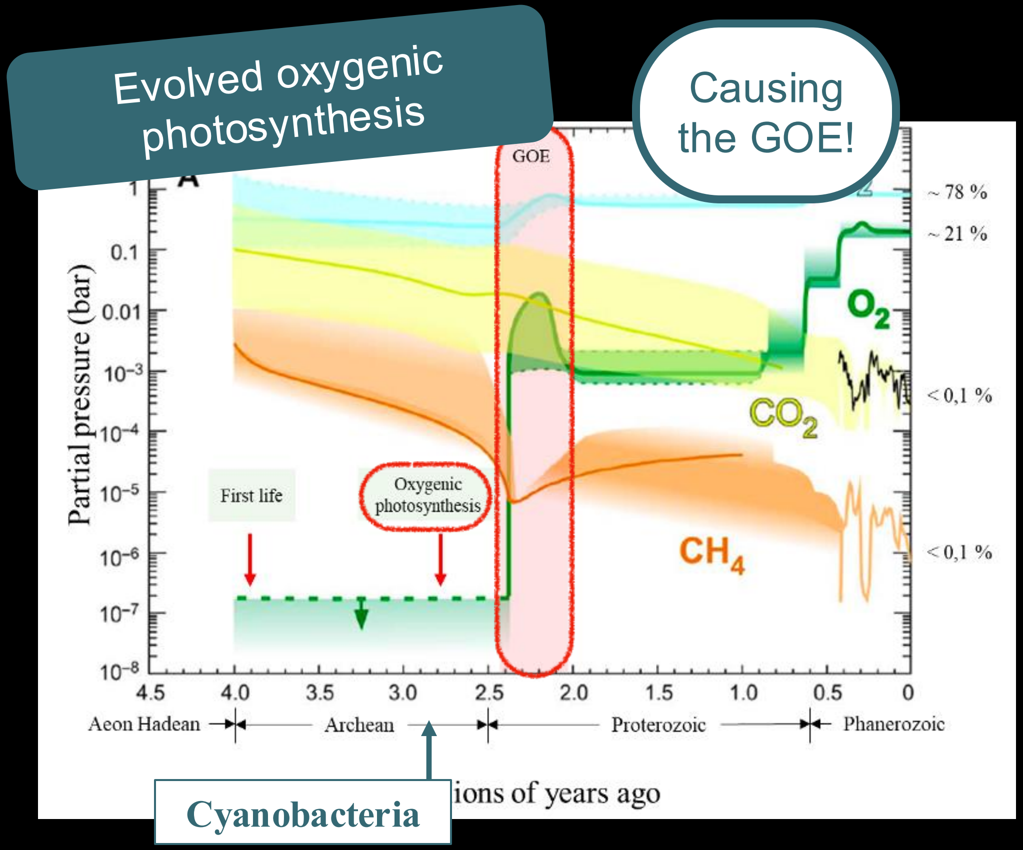


Oxygenic photosynthesis!



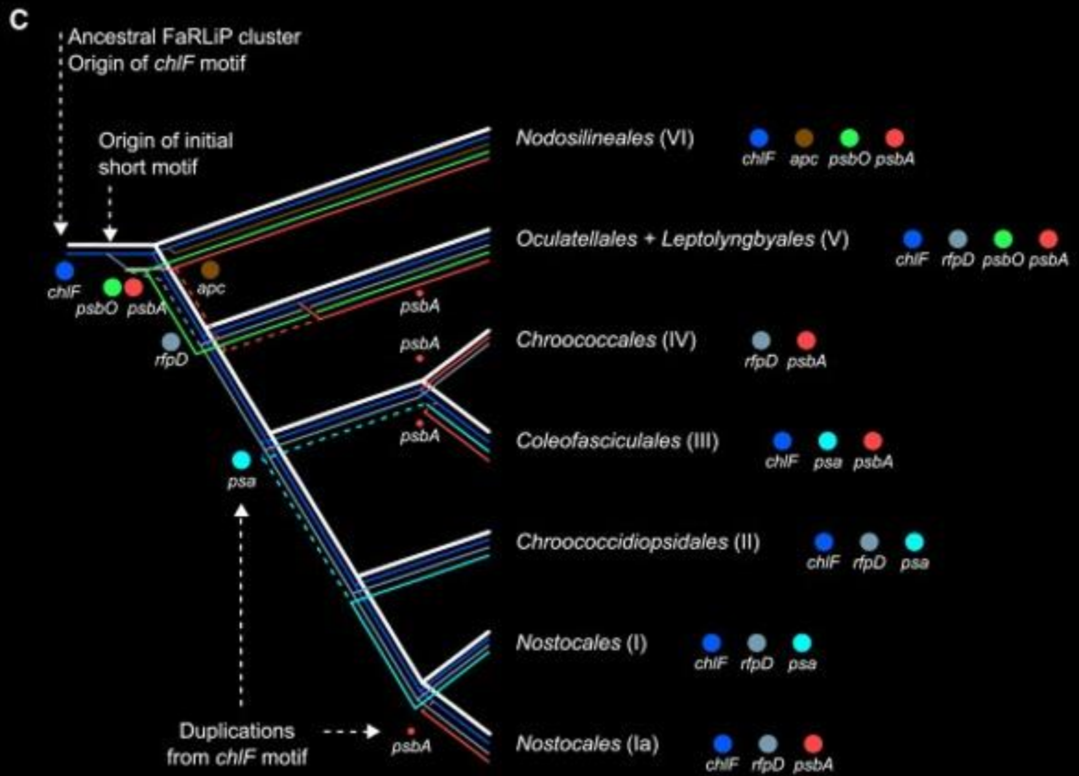


Responses of different photosynthetic organisms: a focus on cyanobacteria



Modified from Catling and Zahnle, 2020; Wandel and Gale, 2020

Ancestral origin of photosynthesis in far-red light



Antonaru et al., 2025

2015-2019

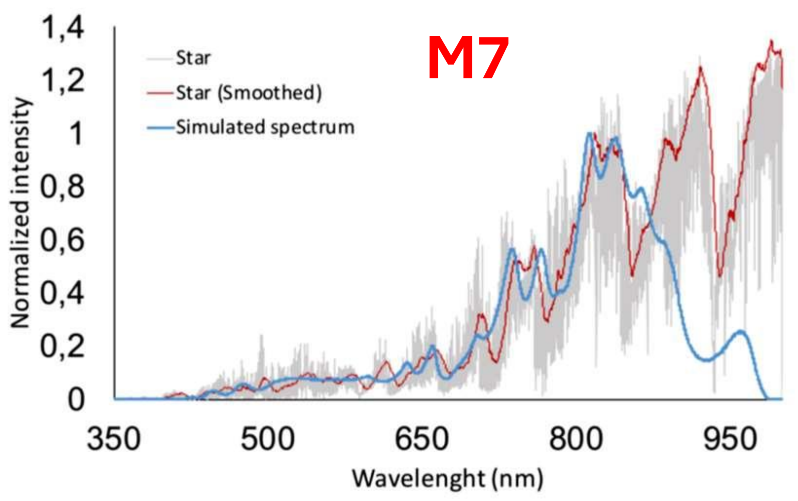
Atmosphere in a test tube (INAF-OAPd)

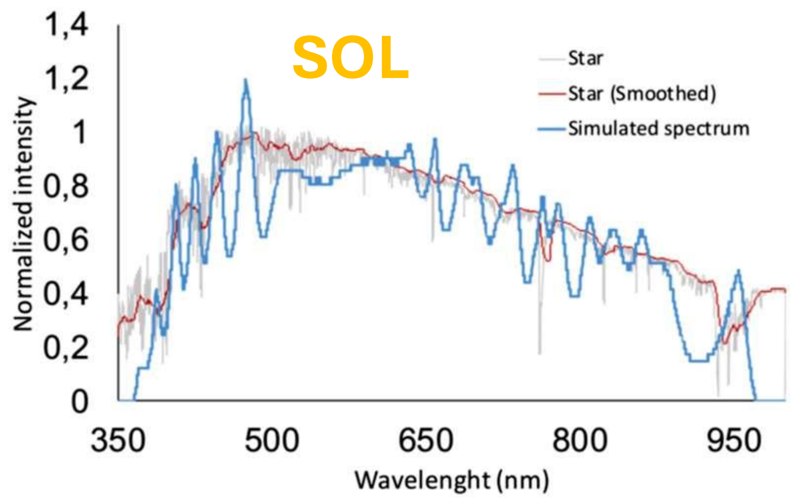
+ CNR / UNIPD grants

Development of the Star Light Simulator (illuminator + PC software)

25 led channels in the 365-940 nm range

Simulates radiation of F/G/K/M star





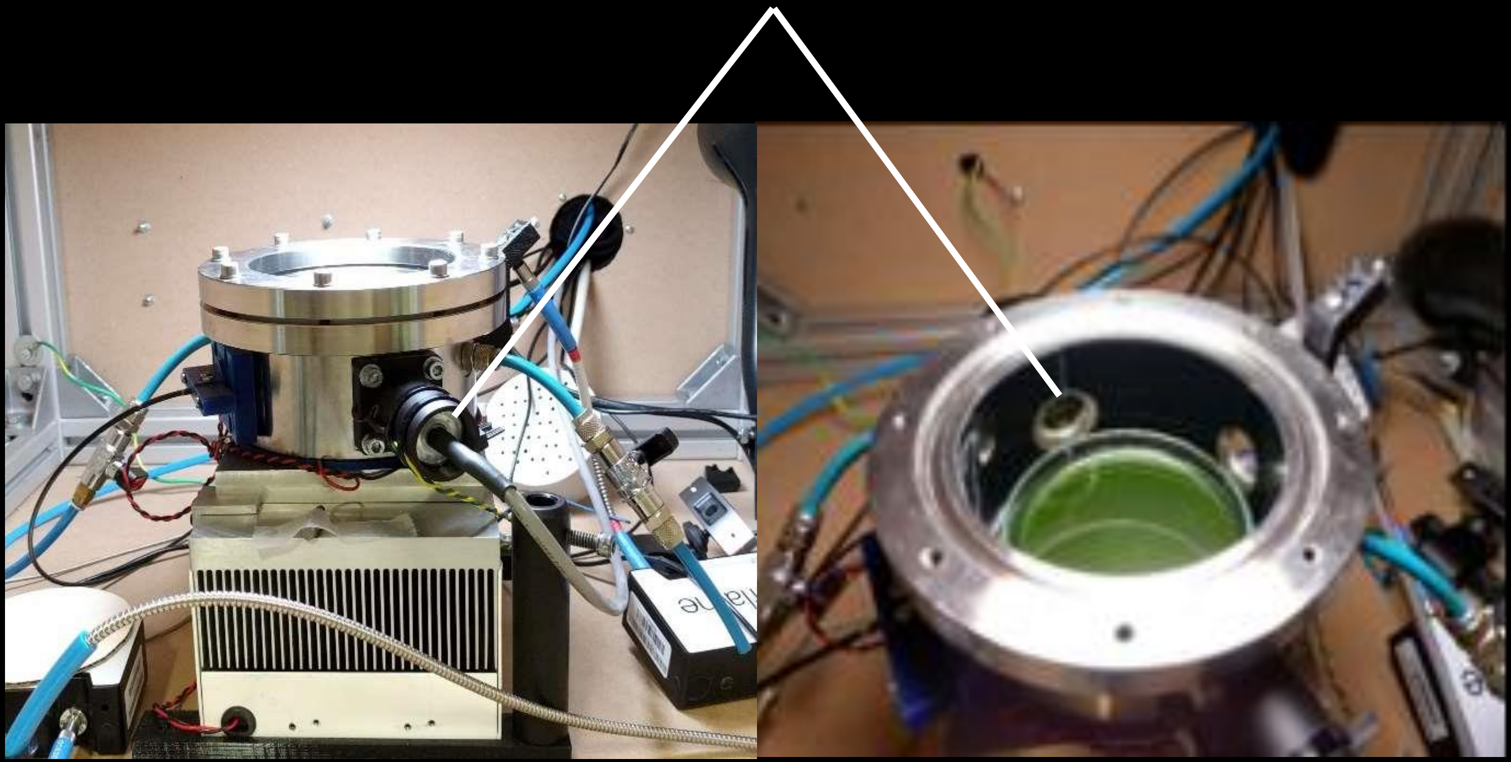
Salasnich et al, 2018

Claudi et al., 2021

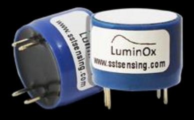
La Rocca et al., 2021

Development of the prototype of Atmosphere Simulating Chamber – ASC

O_2 and CO_2 sensors for real time monitoring



O_2 (SST Sensing)



- LOX-O_2-S

Based on luminescence quenching technology

CO_2 (SST Sensing)

- CO_2M-20
- CO_2M-100

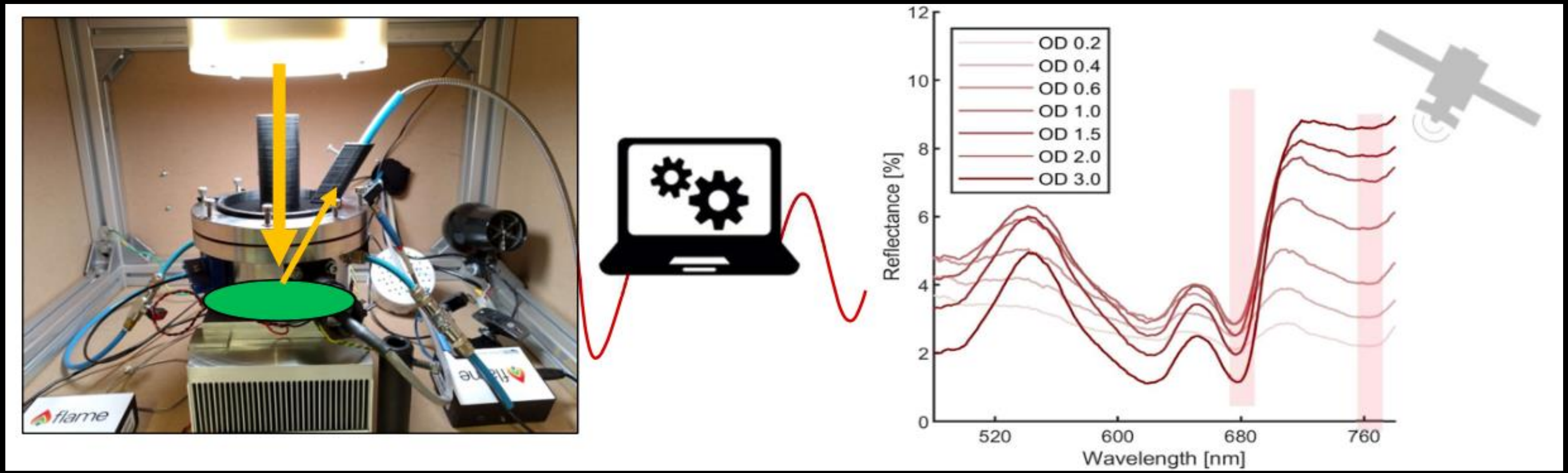
Based on NDIR Spectroscopy

(measurement of absorption band is at 4.26 µm)

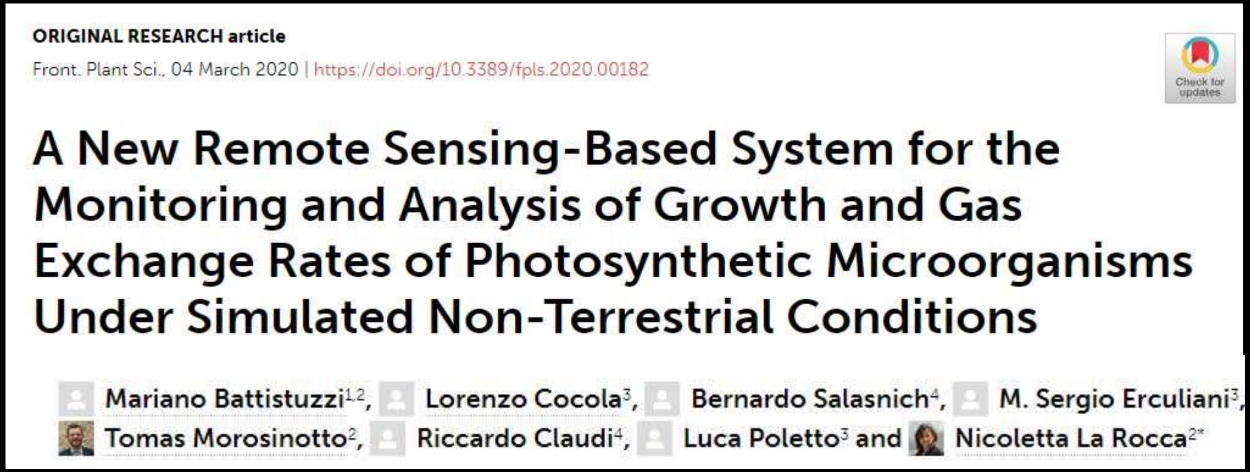
2019-2023
Italian Project of Astrobiology
Life in Space

Reflectance Detection System (RDS)

Reflectance can be recorded directly under the star simulated spectrum or other light sources



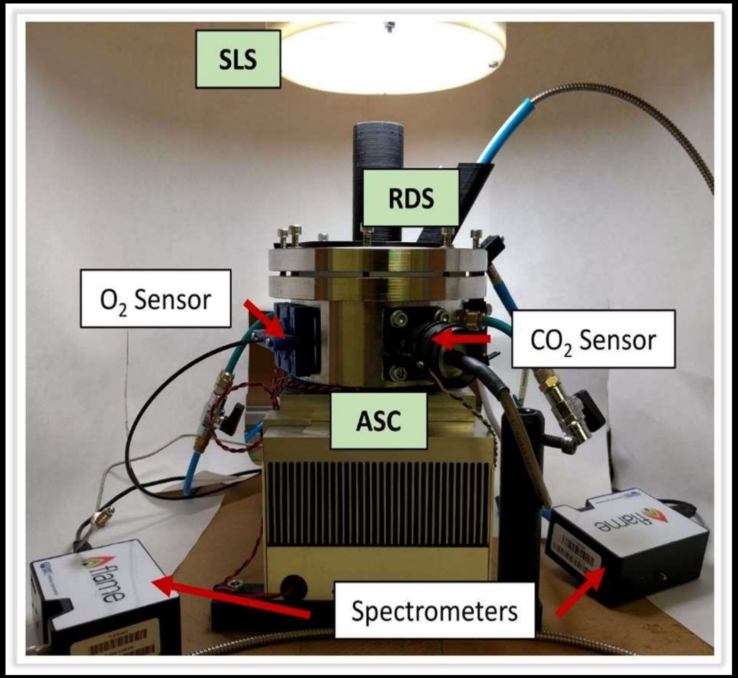
Validation of Atmosphere Simulating Chamber prototype -ASC


ORIGINAL RESEARCH article

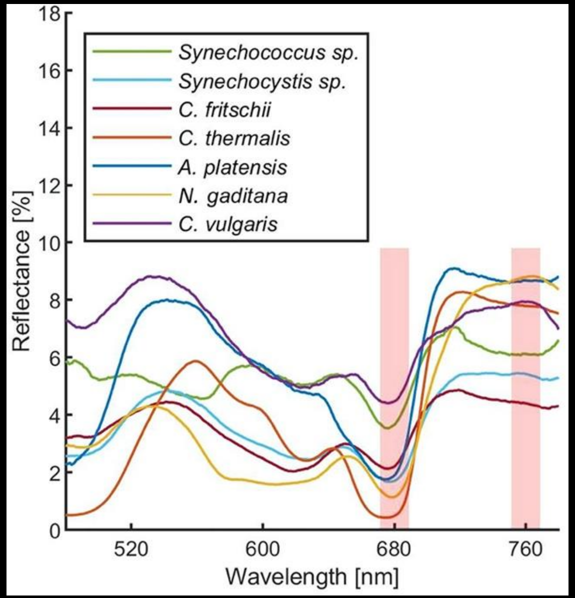
Front. Plant Sci., 04 March 2020 | https://doi.org/10.3389/fpls.2020.00182

A New Remote Sensing-Based System for the Monitoring and Analysis of Growth and Gas Exchange Rates of Photosynthetic Microorganisms Under Simulated Non-Terrestrial Conditions

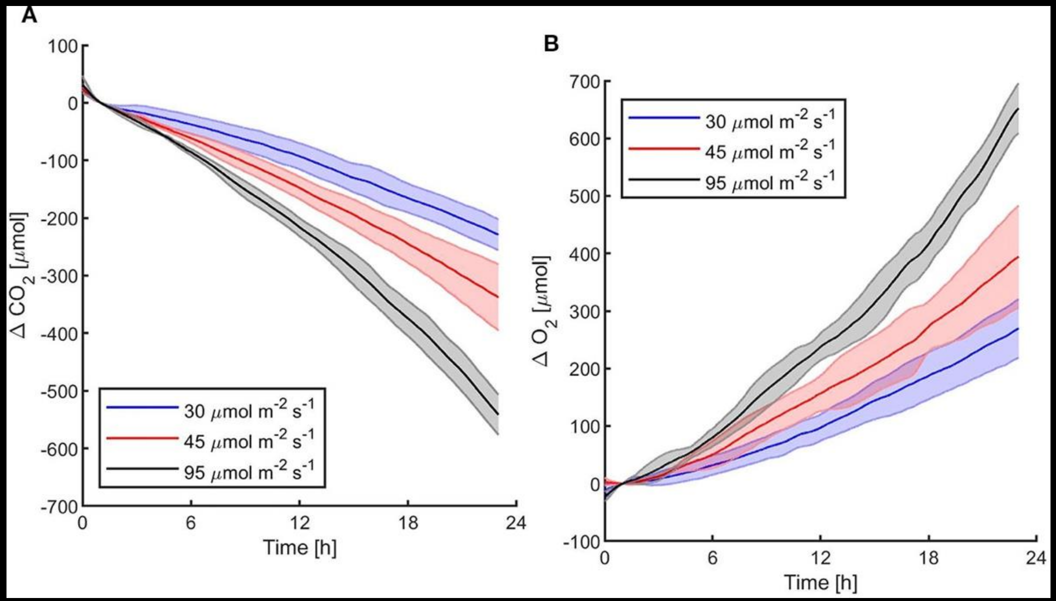
Mariano Battistuzzi[1,2], Lorenzo Cocola[3], Bernardo Salasnich[4], M. Sergio Erculiani[3], Tomas Morosinotto[2], Riccardo Claudi[4], Luca Poletto[3] and Nicoletta La Rocca[2*]



Reflectance spectra

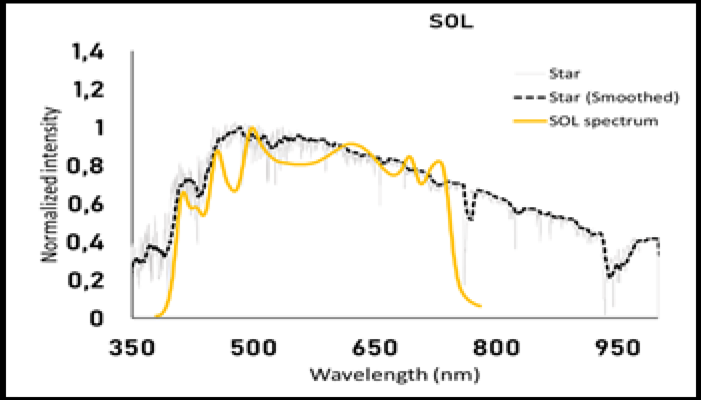


CO_2 consumption and O_2 evolution

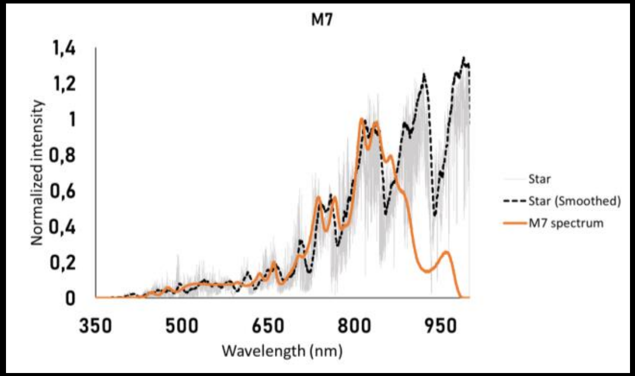


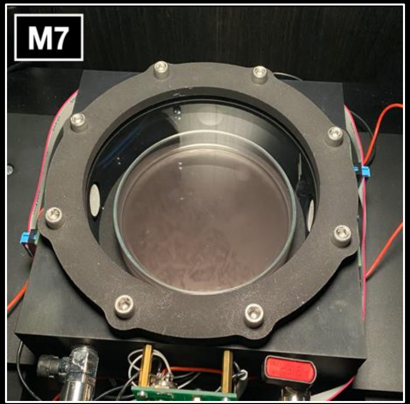
Implementation of the set up:

+1 solar simulator

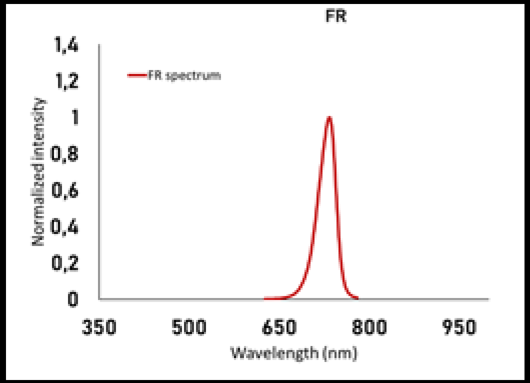


New version of the ASC
for a total of 3 ASCs,
one per light source

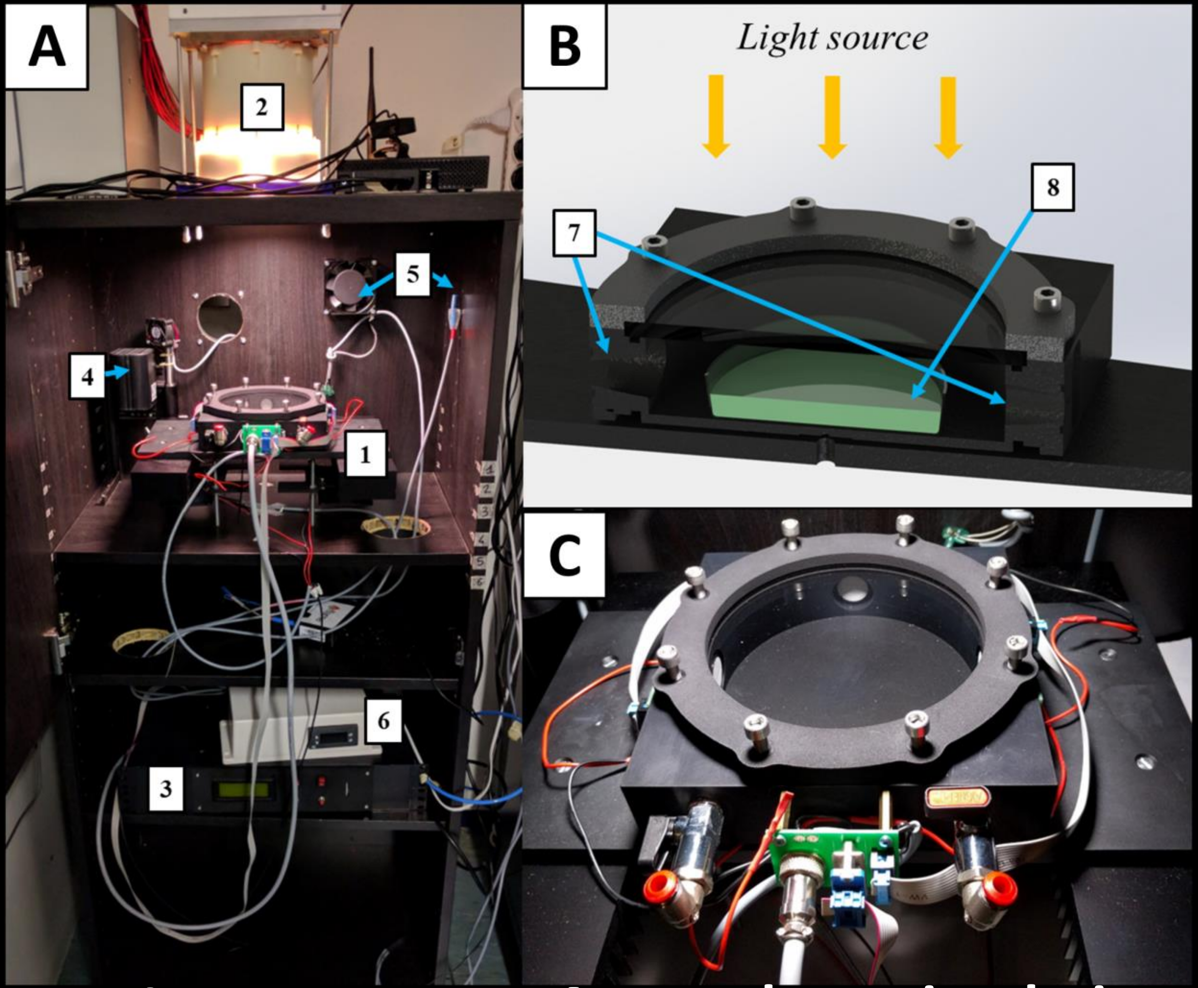




+1 monochromatic FR lamp

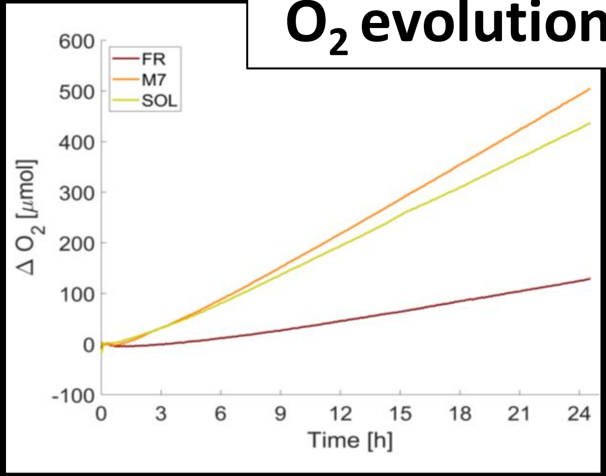


Simulation of planetaty conditions: atmosphere and irradiance

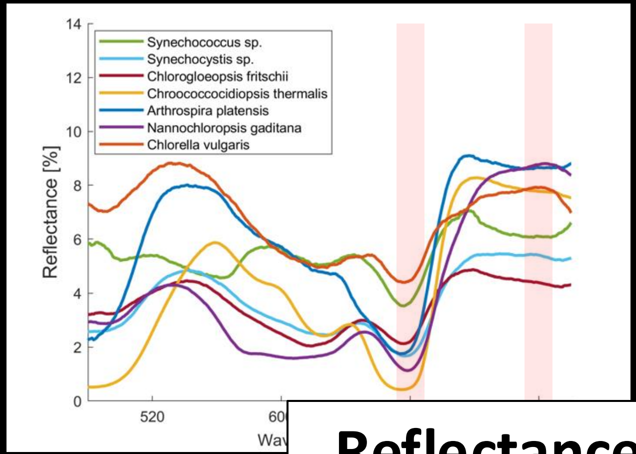


Light simulators

Atmosphere simulating chambers

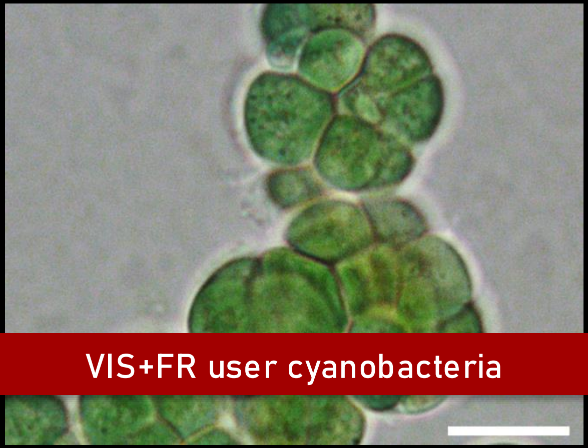


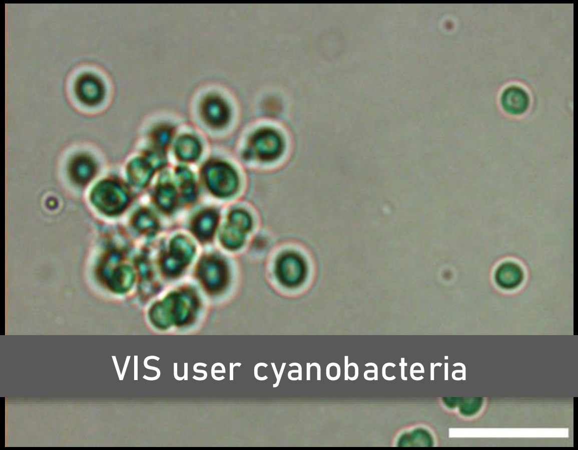
Battistuzzi et al., 2020

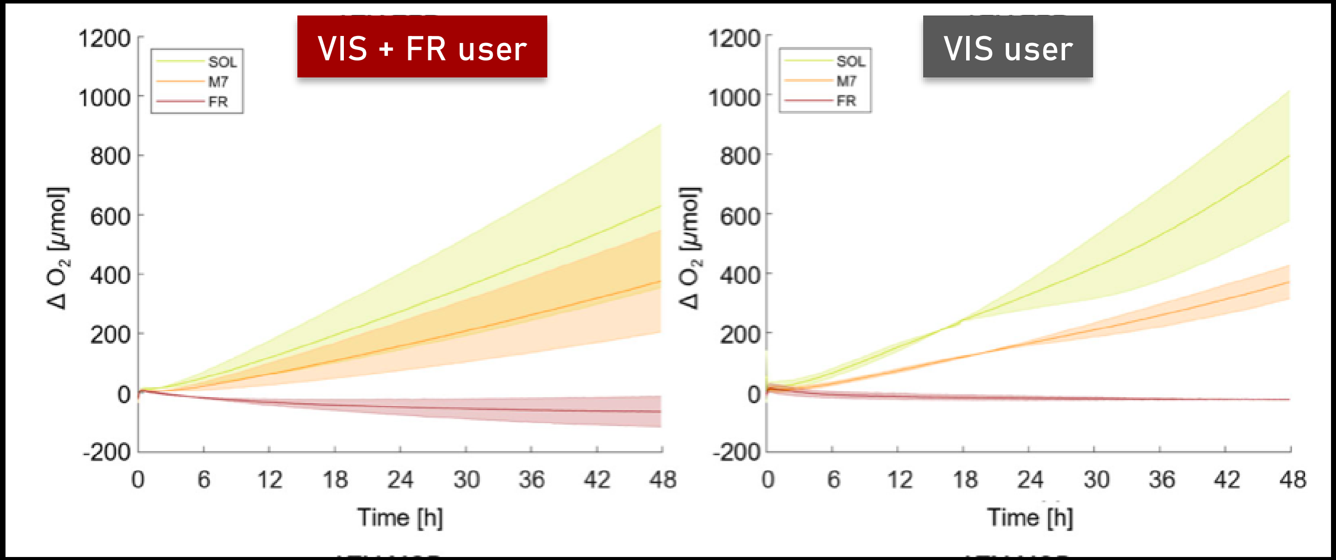


Reflectance

Testing different strains of cyanobacteria in the simulators set up







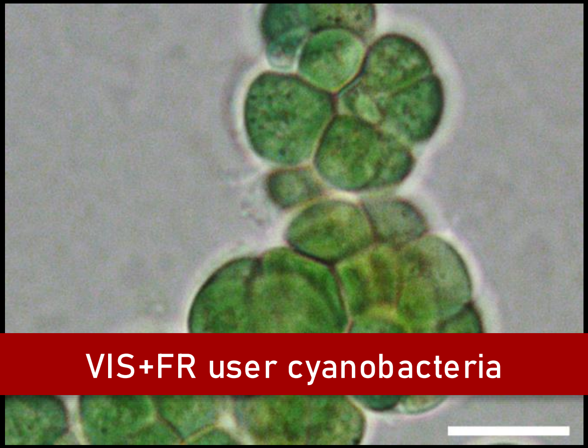
Oxygenic photosynthetic responses of cyanobacteria exposed under an M-dwarf starlight simulator: Implications for exoplanet's habitability

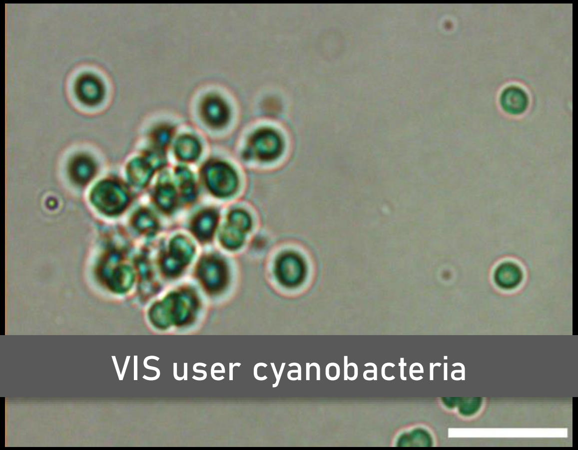
Mariano Battistuzzi[1,2*], Lorenzo Cocola[3], Riccardo Claudi[4], Anna Caterina Pozzer[1,4], Anna Segalla[1], Diana Simionato[1†], Tomas Morosinotto[1,2], Luca Poletto[3] and Nicoletta La Rocca[1,2*]

In the simulated M spectrum O_2 evolution is very efficient in VIS+FR and in VIS user cyanobacteria

USING FR LIGHT IS NOT MANDATORY!

Testing different strains of cyanobacteria in the simulators set up





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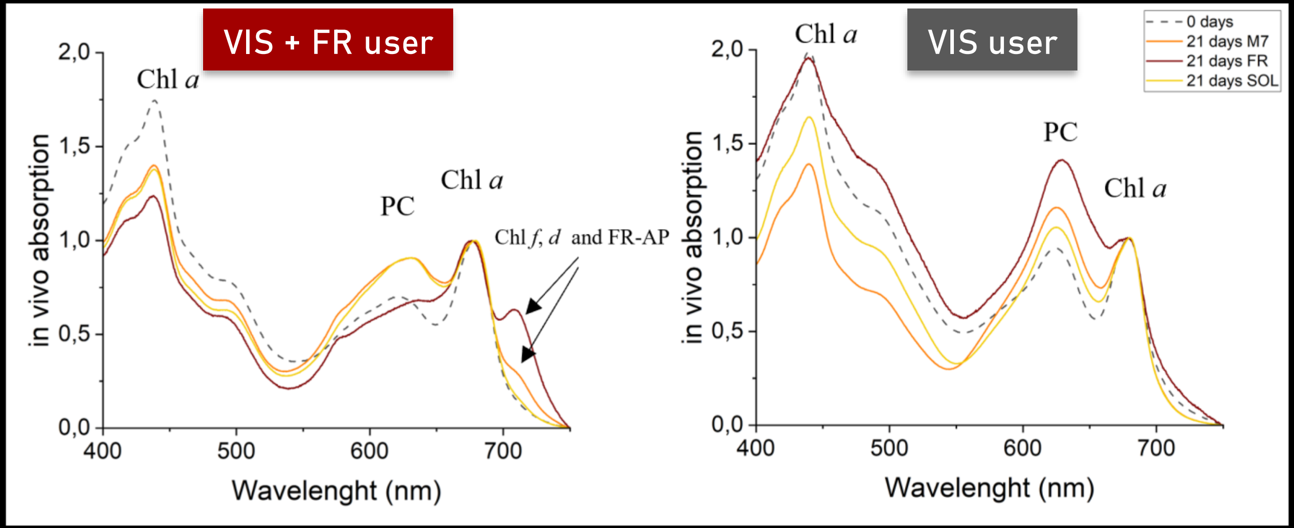
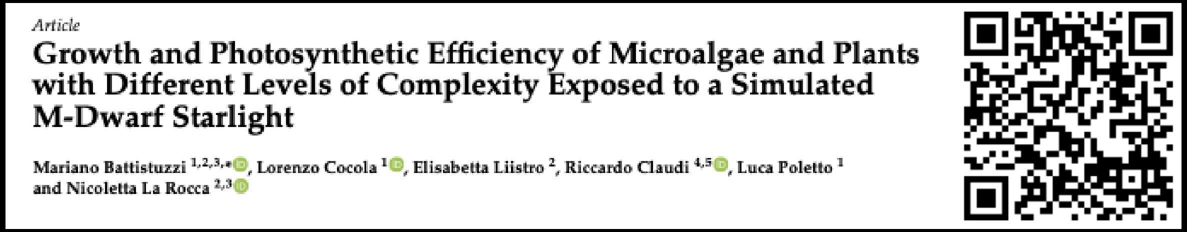


in vivo **spectra differ in the M simulated spectrum, due different pigment ratio or newly synthetized pigments**

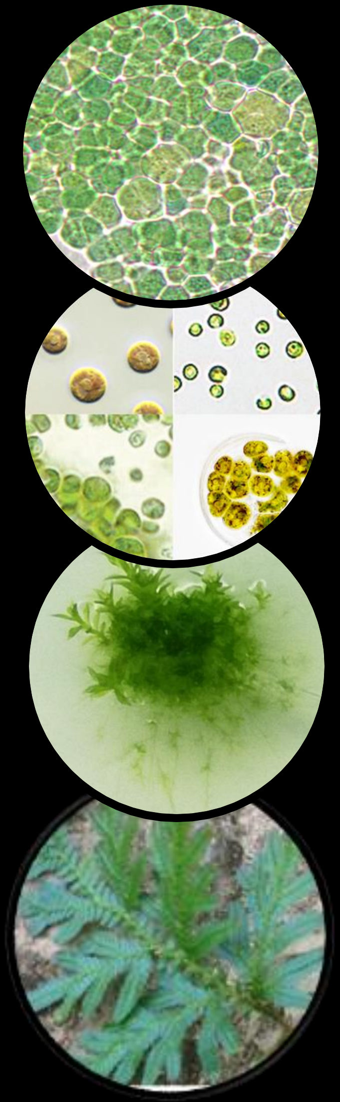
Organisms of higher complexity under simualted M spectrum



Article

Growth and Photosynthetic Efficiency of Microalgae and Plants with Different Levels of Complexity Exposed to a Simulated M-Dwarf Starlight

Mariano Battistuzzi [1,2,3,*], Lorenzo Cocola [1], Elisabetta Liistro [2], Riccardo Claudi [4,5], Luca Poletto [1] and Nicoletta La Rocca [2,3]



Cyanobacteria

Microalgae

→ STRONG GROWTH – NORMAL DEVELOPMENT

Non vascular plant → LIMITED GROWTH – NORMAL DEVELOPMENT

Vascular plants → LOWER GROWTH – ALTERED DEVELOPMENT

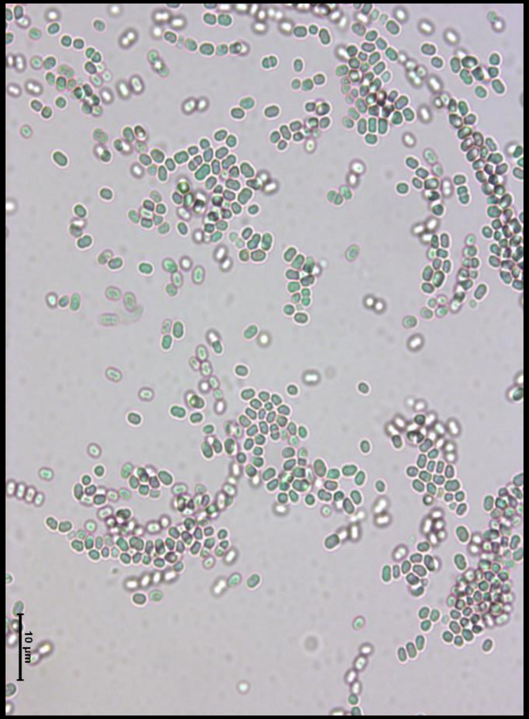
2019-2023

ASTERIA PROJECT

Adattabilità di cianobatteri di ambienti eSTrEmi alla radiazione ultRavIoletta stellAre

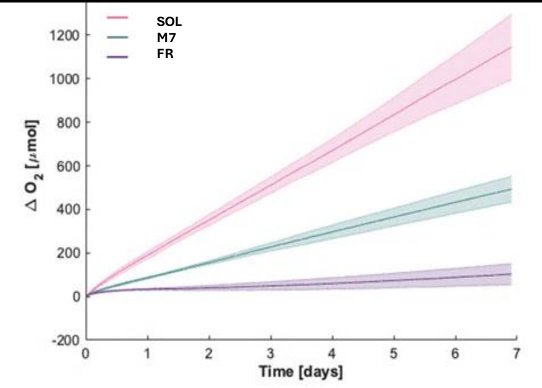
WP UNIPD: Fotosintesi di cianobatteri in condizioni planetarie simulate

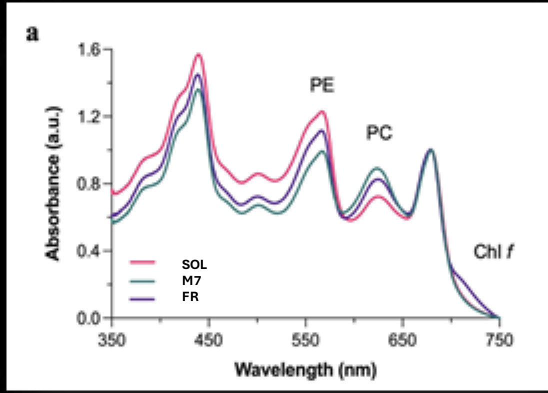
Exposing photosynthetic organisms to stellar radiation and archean/noachian atmosphere



Synechococcus sp. PCC7335 responses to far-red enriched spectra and anoxic/microoxic atmospheres: Potential for astrobiotechnological applications

Elisabetta Liistro [a], Mariano Battistuzzi [a,b,c], Lorenzo Cocola [b], Riccardo Claudi [d,e], Luca Poletto [b], Nicoletta La Rocca [a,c,*]





Photosynthesis is a well conserved but plastic metabolism, that can adapt to different light spectra

An M-dwarf spectrum can sustain this kind of metabolism, showing different responses in different organisms

The study of photosynthetic biodiversity and simulation of planetary conditions can give important hints on what to look for

O_2 evolution rate and possible accumulation

Suitable pigments and possible reflectance spectra

Acknowledgements

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Mariano Battistuzzi
Beatrice Boccia

Luca Poletto
Lorenzo Cocola

Riccardo Claudi

Daniela Billi & team

Laura Silva & team

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Thank you for your attention